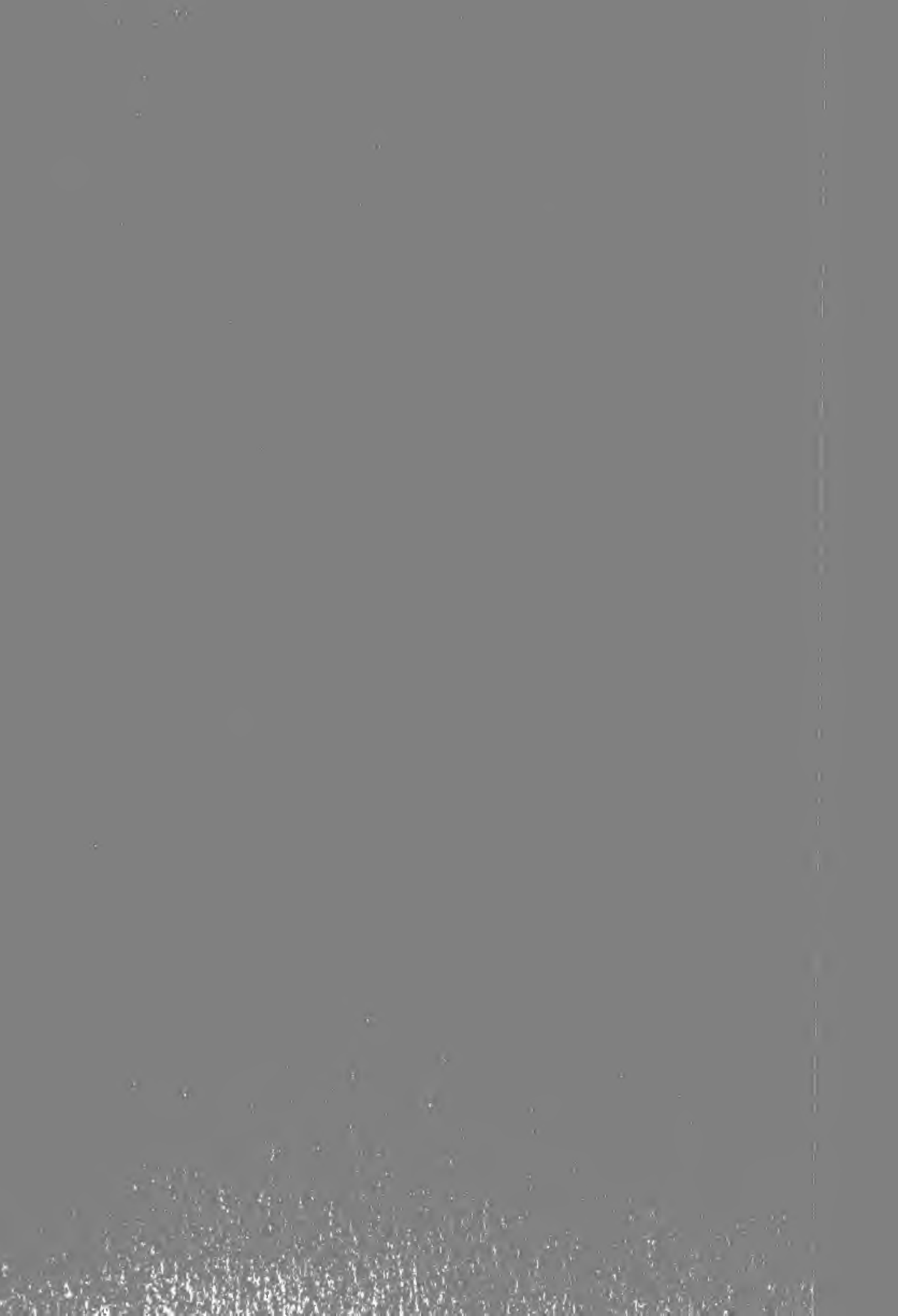


James M. Hill

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THESIS
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AN EVALUATION OF A PROPOSED METHOD OF
LOADING A NAVAL GUN

A Thesis
Submitted to the Faculty
of
Purdue University

by

Cyrus Hugh Butt, III
"

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ABSTRACT

One of the major problems in Naval anti-aircraft gunnery to-day is that of increasing the rate of fire of its anti-aircraft gun in order to maintain pace with increasing aircraft speeds.

The purpose of this study was to analyze the present method of loading the presently installed 5-inch semi-automatic dual purpose anti-aircraft guns, to propose and evaluate an improved method, and to make such recommendations for alteration as may be profitable and feasible.

Films were made of the present method using a 5-inch loading machine to simulate the actual gun. Films supplied by the Naval Proving Ground, Dahlgren, Virginia, of an actual gun firing were analyzed to determine closeness of simulation.

The proposed method was formulated and a rack constructed at the loading machine to fulfill the requirements of the proposed changes.

In evaluating the proposed system a nested factorial design with replications was used for the experimental design for the test. With increase in rate of fire as the criterion for success, two sample loadings of ten rounds rapid fire were obtained from nine loading teams using each method. The sequence of loading was controlled to minimize fatigue and inter-training effects. The loaders were selected into three groups according to weight and height. All loaders had been previously trained in the present method. From five to fifteen rounds practice on the proposed system was given each team before loading for record.

In analyzing the data an analysis of variance technique was used.

A significant difference well below the one percent level was found between methods. The mean rate of fire of the present method was 15.08 rounds per minute, and of the proposed method was 23.58 rounds per minute. No significant difference was found between groups of loaders. No interaction between methods and groups was found. Maximum rates obtained during the test were 19.1 rounds per minute in the present method and 26.9 rounds per minute in the proposed method.

While the method was being filmed for micromotion study, the maximum rate obtained for the proposed method occurred and was equal to 28.8 rounds per minute.

In view of the results obtained in this study, it was concluded that the proposed method is highly desirable and is a considerable improvement over the present method. It can also be concluded from the micromotion studies that even higher rates than were obtained are possible.

It was recommended:

1. That further evaluation be made to determine the maximum performance that can be obtained with fully trained crews, investigating performance at maximum elevation and maximum depression and determining the maximum sustained rate that can be obtained.
2. That a design study be made to determine the feasibility of modifying the hoist system in the manner suggested.
3. That on the basis of this study, a prototype of the ready-service rack proposed as an interim alteration be designed and manufactured for use in the evaluations recommended in (1) above.

4. That prior to re-design of the hoist, a motion study similar to this be conducted in the Upper Handling Room to insure that the supply of ammunition required by the proposed method can be maintained.
5. That a study be conducted to determine a means of ejecting hot cases from the tray at angles of elevation greater than forty degrees.

AN EVALUATION OF A PROPOSED METHOD OF LOADING A NAVAL GUN

INTRODUCTION

In August, 1946, when the Office of Naval Research was established, Secretary of the Navy James Forrestal said, "During a war a nation usually has time only to improve and adapt weapons, the fundamentals of which were evolved during the preceding years of peace. It therefore follows that if a nation is to be scientifically prepared, its preparedness must be worked out in peace time."

Peace time economies and reduced research staffs force a large portion of our efforts to be concentrated on new weapons at the possible expense of making the best improvements on our present weapons. The NAVORD OrdAlt program is designed to provide means for making improvements on existing weapons. However, the cognizant research sections, responsible for equipment changes, find it difficult to do more than rectify reported defects, while hard at work on their next assignment. Indeed, some Ordnance Engineers feel that it is less expensive to design a new weapon than to attempt major design improvements on existing weapons. This may be because too great a change is attempted.

Men in the Fleet spend many long hours training and working toward obtaining maximum utilization of the excellent weapons provided, yet they can seldom realize the full capabilities for which the weapons were designed. Why? Part of the answer may come from the fact that when development of new weapons is nearing completion, the pressing

need for these weapons in the Fleet all too often makes it expedient to go into production before design changes indicated during preliminary testing and evaluation can be incorporated. The author has felt for a number of years that possible improvements in this area between production and service utilization may be greater than is realized. Certainly Industrial Engineers in industry have proven with many notable examples that great and valuable improvements can be made on existing equipment and methods often at relatively small expense.

The weapons development program of the Naval Bureau of Ordnance is designed to utilize maximum benefits from research and technological improvements. The research efforts of military, educational and industrial activities are continually drawn upon by the project engineers, yet, again, circumstances do not permit them to do all that they would like to do.

Gunnery men have always sought to increase their range, accuracy, and rate of fire. In the advent of higher and higher speed aircraft, these factors have become even more important in order for the guns to be effective. During World War II our best anti-aircraft gun was the five-inch semi-automatic dual purpose gun, capable of sustained fire of fifteen rounds per minute with a maximum rate of fire ever obtained of twenty-two rounds per minute being reported. This gun has a semi-automatic sliding breech mechanism, hydraulic recoil and hydro-pneumatic recuperator systems, and a power rammer mounted in the slide gun-loading tray. The power rammer operates to ram ammunition at all positions of gun-laying movement. Ammunition is fixed, two-piece, comprising

a 54-pound projectile and a 28-pound powder case. Ammunition is manually served to the gun-loading tray¹.

These guns were good guns, but continued increase in speed of aircraft without comparable increase in rate of fire has acted to reduce their effectiveness. New anti-aircraft guns with higher rates of fire have been designed and many of lighter caliber (3"/50) have been installed. However, there are still several thousand 5-inch guns in the Fleet, and with an economy-minded Congress they are not likely to be replaced except on the larger ships.

A new 5-inch automatic rapid firing gun has been developed, but the considerable increase in weight of this gun over the presently installed semi-automatic guns makes it impractical to replace the semi-automatic on the smaller combatant ships, even if the funds were available. The presently installed 5-inch twin mount is approximately twenty tons lighter than the new 5-inch full automatic single mount.

If the rate of fire of the presently installed guns could be materially increased without too difficult and expensive modification, then the Fleet would realize an increase in effectiveness with its present guns. These guns are capable of much higher rate of fire than has been realized.

The purposes of this study were to analyze the present method of loading the 5-inch 38 caliber gun, to propose and evaluate an improved method, and to make such recommendations for alteration that may be profitable and feasible.

1. "Five-inch Gun Mounts 38 Caliber--AA-Type," Ordnance Pamphlet No.

DEVELOPMENT OF THE PROPOSED METHOD

The author presupposes that those most interested in this study will be acquainted with the equipment and terminology used, and will therefore hold definitions and descriptions to the minimum required for proper identification.

The pattern followed in the development and evaluation of the proposed method was based upon the scientific method of problem solving as suggested by Mundel², Davis³, and others.

Criterion for Evaluating Proposed Method

As previously stated, the objective was to propose a new method of loading the 5-inch semi-automatic gun that would permit an increase in the rate of fire. The criterion for evaluating the preferability or success of the solution is therefore the increase in rate of fire in rounds per minute realized.

The areas of the job considered for change were as follows:

1. The manner in which the powderman and projectileman load the gun.
2. The manner in which the rammer is controlled.
3. The manner in which the ammunition is presented to the loaders, that is, the location of the projectile hoist and the powder hoist.
4. The manner in which the breech block is opened after firing.

No attempt will be made to provide a complete design of proposed material changes, but rather to provide the general requirements of

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2. Mundel, Marvin E., Motion and Time Study; New York, Prentice-Hall, Inc. 1950.
 3. Davis, Ralph Currier, Industrial Organization and Management; New York, Harper and Brothers, 1940.

such a system leaving as much latitude as possible to the Design Engineer.

Analysis of Present Method

Complete information on the characteristics and elemental cycle time of the loading machine and actual gun was not available. The following data were obtained from Ordnance Pamphlet No. 735⁴ and the 5-inch semi-automatic gun Project Engineer, Research Section, Bureau of Ordnance.

1. Projectile hoist cycle time	1.75 seconds per round
Specification maximum	2.00 seconds
2. Rammer ram stroke	0.55 seconds
Specification maximum	0.75 seconds
3. Rammer retract stroke	0.45 seconds
4. Gun recoil	0.12 seconds
5. Gun counter recoil	0.38 seconds, of which the last inch of return to battery requires 0.20 seconds.

In view of the scarcity of known performance data available, pictures (for film analysis) were taken at 16 frames per second of a selected team loading by the present method on the 5-inch loading machine. Also, films were obtained from the Naval Proving Ground, Dahlgren, Virginia, taken at approximately 100 frames per second of the rammer cycle and actual firing cycle of a 5-inch 38 gun.

The equipment used in the study was a standard, right-hand, 5-inch loading machine with a Northern Pump rammer (late design). Loading crews were obtained from volunteers from the freshman and sophomore classes of the Purdue University Naval R.O.T.C. Unit. GM 1 H. D.

4. "Five-inch Gun Mounts 38 Caliber," op. cit.

Hughes, U.S.N., acted as Gun Captain during all loading.

The results of the film analysis of the loading machine film and the actual firing film are tabulated in Tables 1 and 2, and charted in Figure 1. The rate of loading of the loading machine crew was 17.8 rounds per minute, approximately the rate obtained by a well-trained loading crew during short periods of fire. See Figures 2, 3, 4, and 5.

Critical Examination of Present Method

Barnes⁵ provides twenty-two principles of Motion Economy. Those considered pertinent to this study are listed below:

1. "The two hands should begin as well as complete their motions at the same time.
2. "The two hands should not be idle at the same time except during rest periods.
3. "Motions of the arms should be made in opposite and symmetrical directions, and should be made simultaneously.
4. "Hand motions should be confined to the lowest classification with which it is possible to perform the work satisfactorily.
5. "Momentum should be employed to assist the worker wherever possible, and it should be reduced to a minimum if it must be overcome by muscular effort.
6. "Smooth continuous motions of the hands are preferable to zigzag motions or straight-line motions involving sudden and sharp changes in direction.

5. Barnes, Ralph M., Motion and Time Study; New York, John Wiley and Sons, Inc., 1949, p. 191.

TABLE 1

RESULTS OF FILM ANALYSIS - PRESENT METHOD

Machine Analysis

Description	Loading Machine Time in seconds	Actual Gun Time in seconds
Operate control lever	0.13	0.13
Ram stroke	0.62 ¹	0.55 ³
Breech Block Closed	0.18	0.15
Firing occurs a few milliseconds after breech block closes		
Gun Recoil	---	0.11 ³
Counter Recoil to Breech Block begins to open		0.12
Breech Block open - ejection begins		0.06
Last 1" of Counter recoil		0.20
Total Counter recoil		0.38 ³
Rammer retract stroke	0.75 ¹	0.41 ³
Hot Case clear after firing	1.00 ¹	0.65
Rammer Retract complete to Hot Case Clear	0.25	0.23
Drop Spade	0.12	
Total Cycle - Commence ram to Hot Case Clear (Ready for next round and spade to be dropped)	1.93	1.48
Ram Stroke commenced to Hot Case Clear	1.80	1.35
Breech Block open to Hot Case Clear		0.36

Note 1: Loading Machine Rammer is operating near the upper specification limit causing Hot Case Clear cycle and total cycle to be longer than actual firing cycle.

Note 2: Loading Machine depends on Rammer Retract to open breech block and cause ejection of hot case. In actual gun, counter recoil furnishes force to open breech block and cause ejection of Hot Case in approximately the last six inches of return to battery.

Note 3: Information obtained from Bureau of Ordnance confirmed in film analysis.

Percent Machine Utilization at 17.81 Rounds per Minute

$$= \frac{\text{Machine Cycle}}{\text{Total Cycle}} \times 100 \quad 57.2 \quad 40.0$$

TABLE 2

RESULTS OF FILM ANALYSIS - PRESENT METHOD

Man Analysis (17.8 rounds per minute)

Projectileman

Therblig	Description	Time in seconds
G	Grasp rammer control lever	0.06
U	Operate control lever	0.13
RL	Release control lever	0.08
TE	To hoist	0.25
G	Grasp projectile	0.06
U	Depress foot pedal	0.06
DA	Remove projectile from hoist	0.94
TL	To loading tray	1.20
PA	Place in tray and steady	0.38
RL	Release projectile - ready for ram	0.05
TE	To rammer control lever	0.18
TOTAL CYCLE TIME		3.37
Rate: Rounds per minute 17.8		
Time to control ram (TE, G, U, RL)		0.45
Estimated Time to Load without controlling rammer		2.92
Estimated Rate when not controlling rammer.. 20.5 rounds per minute		

Powderman (17.8 rounds per minute)

G	Grasp powder case	0.12
DA	Remove from hoist	0.25
TL	To erect position-case at port	0.37
UD	Wait for hot case ejection	0.94
PA	Load in tray	0.19
RL	Release powder case	0.06
TE	Turn toward hoist	0.12
UD	Waiting for hot case man to fill hoist	0.94
TE	Bend and reach for next round	0.37
TOTAL CYCLE TIME		3.37
CYCLE TIME LESS WAITING (UD)		1.49
Time to bend and rise to erect stance		0.74

Note: Waiting for hot case man to fill hoist would not occur in actual mount. This wait would then be added to "wait for hot case ejection" and total would be less than 1.88 seconds since the hot case clears faster in actual firing by approximately 0.45 seconds. (See Machine Analysis).

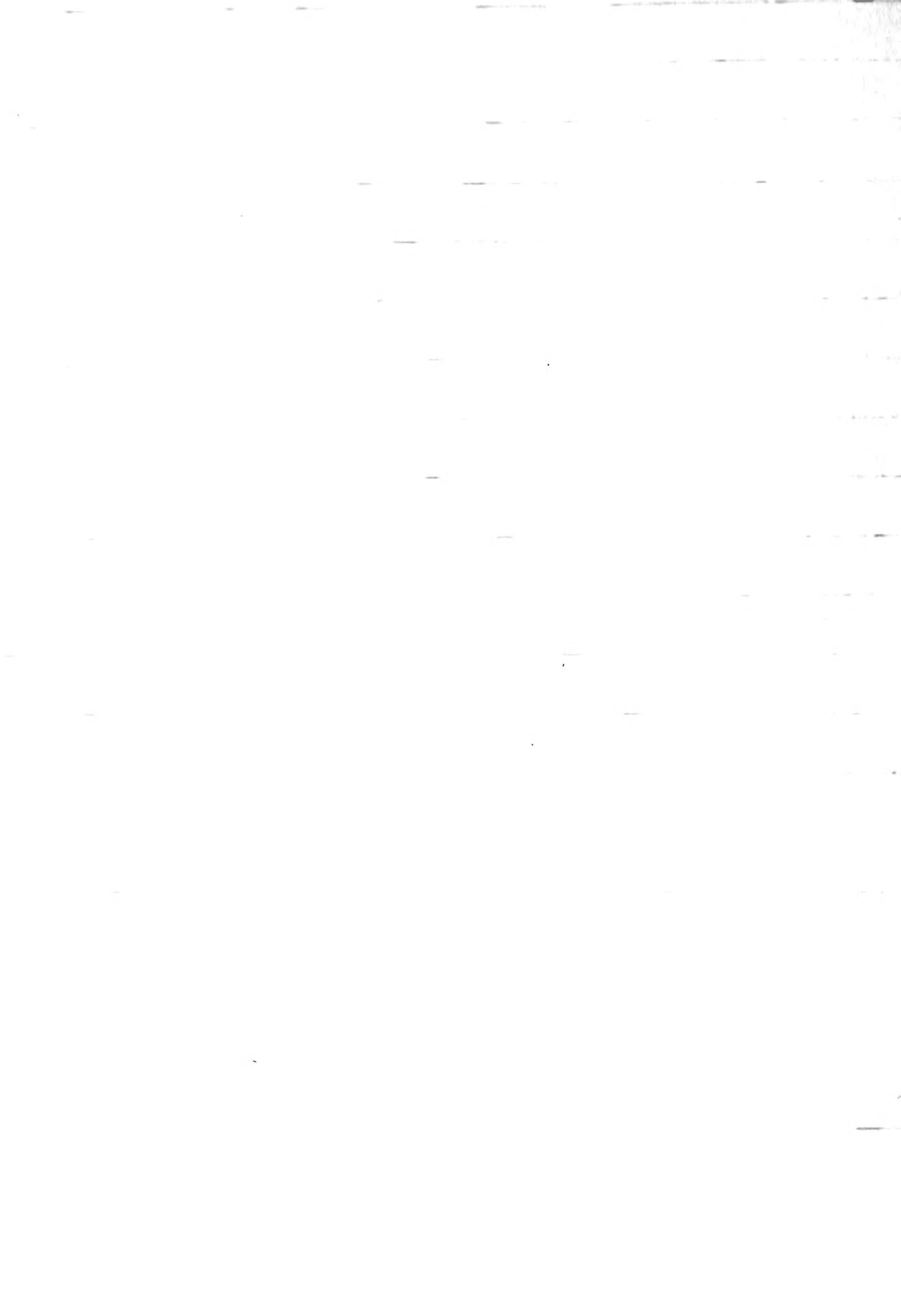


Fig. 1
Cycle time of Loading Machine and Actual Gun

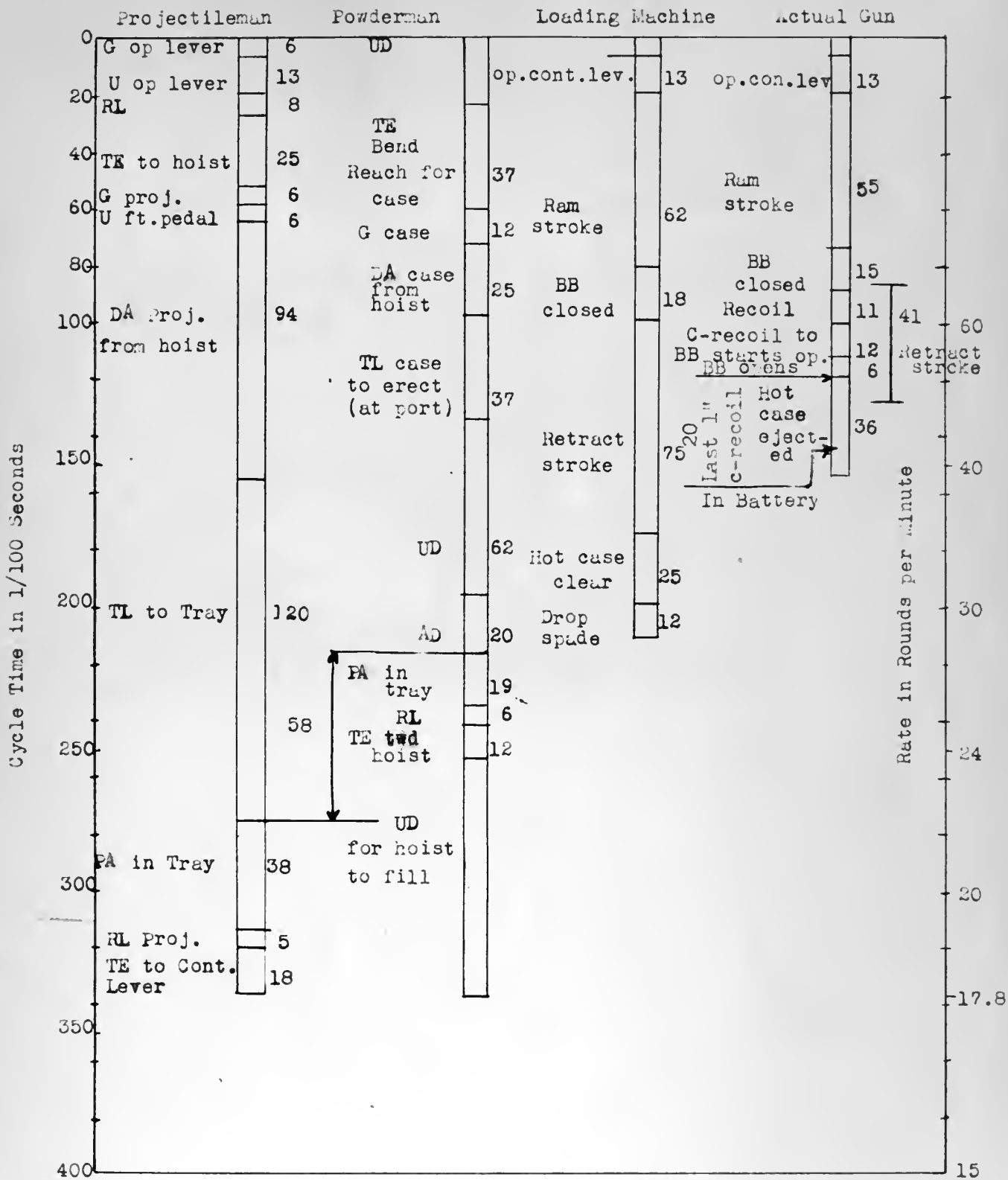




Fig. 2

A view from aft of the loading machine and crew, showing the present method.

- Conditions:
1. Rammer completing ram stroke.
 2. Powderman bending and reaching for powder case.
 3. Projectileman commencing DA projectile from hoist.





Fig. 3

A view from aft of the loading machine
and crew showing the present method.

- Conditions:
1. Rammer retract stroke in progress
 2. Powderman straightening up with powder case (TL)
 3. Projectileman completing DA from hoist, ready to commence TL to tray.



Fig. 4

A view from aft of the loading machine
and crew showing the present method

Conditions: 1. Powderman RL powder case

2. Projectileman TL projectile-Note:

Grasp of right hand on base must be changed to upper side during
PA projectile.



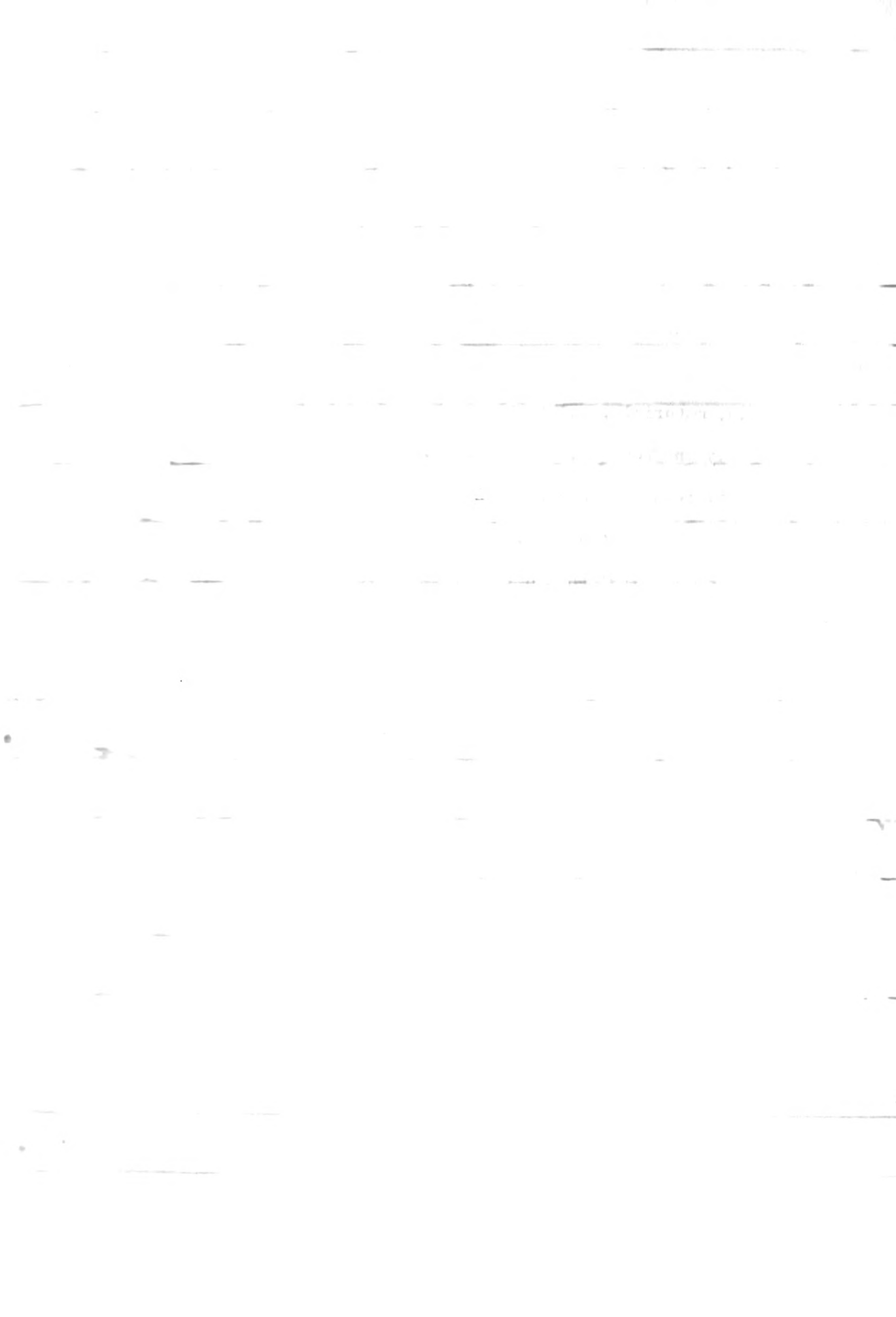
Fig. 5

A view from aft of the loading machine
and crew showing the present method

- Conditions:
1. Round in tray, projectileman grasping rammer control lever to initiate ram.
 2. Powderman turning toward powder hoist for next round.

7. "Ballistic movements are faster, easier, and more accurate than restricted (fixation) or 'controlled' movements.
8. "Rhythm is essential to the smooth and automatic performance of an operation, and the work should be arranged to permit easy and natural rhythm wherever possible.
9. "There should be a definite and fixed place for all tools and materials.
10. "Tools, materials, and controls should be located close in and directly in front of, the operator.
11. "Gravity feed bins and containers should be used to deliver materials close to the point of use.
12. "'Drop deliveries' should be used wherever possible.
13. "Materials and tools should be located to permit the best sequence of motions."
14. "The hands should be relieved of all work that can be done more advantageously by a jig, fixture, or a foot-operated device."
15. "Levers, crossbars, and hand wheels should be located in such positions that the operator can manipulate them with the least change in body position and with the greatest mechanical advantage."

An examination of the data obtained from the film analysis immediately pinpoints the projectileman as the "bottle-neck". The machine cycle, from the time the rammer is operated until the spade is dropped for the next round, is 2.06 seconds as compared to 3.37 seconds for the complete cycle. The powderman's minimum cycle is shorter than the



machine or gun cycle, forcing him to wait for the ejected case to clear. Although the fact that the powderman must bend almost to the platform to get the case is a violation of principles 6 and 10, his job is not considered critical.

The projectileman grasps the base of the projectile, while stepping on the foot pedal. He must then force the projectile past the spring loaded hoist door, turning the projectile to the horizontal, catching the nose with his other hand while turning his body 90° to face the loading tray. At the same time, the downward momentum of the 54-pound projectile must be stopped and reversed and the projectile lifted in varying degrees, depending upon the elevation of the gun, and moved into the loading tray in a direction 90° from initial motion. As the projectile is deposited in the tray, the grasp on the base must be changed quickly to the upper side in order to avoid the hand being caught between the projectile and the powder case. The projectile is then steadied. In order to insure that this hand is removed from between the projectile and case, projectilemen are required to use this hand to operate the control lever of the rammer. This requires a body turn of about 45° . After initiating the ram stroke, he turns to the alternate tube of the hoist for the next projectile. The projectileman, therefore, is forced to violate principles 1, 4, 5, 6, 7, 8, 9, 10, 13, 14, and 15.

The necessity of operating the rammer lengthens the projectileman's cycle 0.45 seconds and breaks the rhythm of his motion. It does not always insure that the round is ready for ramming, particularly for the inexperienced loader, for in reaching for the operating lever

he turns away from the round and sometimes fails to see that he has not steadied the projectile. In addition, if he, in his haste to get the next round, does not completely pull the operating lever down, he may load the next projectile on top of an unrammed round. The Gun Captain could easily and safely initiate the ram if he had a control lever at his station. If the projectileman did not have to grasp the projectile by its base, he would not have to change grasp or risk mashing his hand. Clearly, considerable improvement could be made by changing the location of the projectile hoist and eliminating the operation of the rammer from the projectileman's duties.

Comparison of the machine cycle of the loading machine to the machine cycle of actual firing shows that this loading machine is 0.6 seconds slower. Part of this is due to poor rammer adjustment. Better performance was obtained during the movies of the proposed method.

Formulation of the Proposed Method

A system and procedure proposed is as follows:

1. That the powder and projectile be presented to the loaders at a position 80 inches above the platform and from 2 to 10 inches horizontal distance from the path of the closest edge of the housing to the loader, in such a position that the ammunition is above and in front of the normal position of the loader for placing the round in the tray. This will permit the tallest enlisted man to stand under the ammunition, and will also be sufficiently high to permit rounds to be loaded, without lifting, at the maximum angle of depression of the gun.

2. That the ammunition be so suspended that the loader may grasp the round with both hands, thumbs toward the gun, and that the suspended round may be released into the hands by the action of a foot pedal in such a manner that it may be moved out laterally and downward toward the tray.
3. That the control lever for the rammer be installed at the Gun Captain's station.
4. That the breech mechanism be altered so that the breech is opened during recoil rather than during the last few inches of counter recoil. This change is not vital, but has been done on the new full automatic 5-inch and would shorten the machine cycle time by 0.23 seconds. Since the time required for ejection of the hot case is less than that for rammer retract, it may also be possible to permit the spade to drop automatically.

The loading procedure will be as follows:

1. The loaders would grasp the round, depress the foot pedal and, after clearing the mechanism, swing the round in a ballistic arc into the tray, steadying it with both hands before releasing. For high angles of fire, the round should be lowered vertically downward to about chin level before swinging the round into the tray.
2. The Gun Captain, upon observing the round properly loaded and steady, would operate the rammer control lever.
3. The loaders would then reach for the next round and wait until the tray is again ready for loading. This readiness should be anticipated in releasing the next round, particularly by the powderman.

The above requirements can be met by re-designing both hoists to extend upward from the present projectile hoist position and curve over the heads of the loaders to the positions described. It would be preferable that the projectile hoist be of the single tube, endless chain type; however, it is not considered that the present type hoist would materially affect performance if extended to the proposed position, although this would violate motion economy principle number 9.

As an interim installation, pending re-design of the hoist, a simple chain conveyor ready-service rack with delivery point and releasing mechanism as proposed above and extending across the top of the mount, could be designed for installation by tenders or navy yards. It is estimated that approximately 20 rounds might be held by such a rack for initial attacks.

EVALUATION OF PROPOSED METHOD

Preliminary Analysis

Preliminary analysis of the proposed method reveals that the principles of motion economy (see page 6) have been complied with in the following manner:

1. The two hands begin as well as complete their motions at the same time. The hands are not idle at the same time except during the "Wait" for the hot case to clear. Some "Wait" is not undesirable since it has been found that a pace increase is possible when each cycle contains rest⁶. Motion of the arms is symmetrical although not opposite, but is made simultaneously. Hand motions are still of high classification requiring use of the full arm; however, the ammunition is located close and in front of the operator. No "side steps", "body turns", "body bends", or "material turns" are required except by the powderman at high angles of fire. The system of Methods-Time Measurement⁷ assigns definite time values to such elements. Gravity does most of the work and momentum assists the loader. There are no sudden or sharp changes in direction and the ballistic type movement should make the loading faster, easier, and more accurate.

6. Llewellyn, R. W., "An Investigation of the Effects of Machine Time on Operator Pace," Master of Science Thesis, Purdue University, 1948.

7. Maynard, H. B., Stegemerten, G. J., Schwab, J. D., Methods-Time Measurement; McGraw-Hill Book Company, Inc., New York, 1948.

2. The operation of the rammer has been eliminated from the projectileman's duties.

It seems logical to expect that the above changes and economies of motion make the loader's job easier, faster, and less fatiguing. The method is less complicated and training should tend to reduce the effect of individual differences⁸. In view of the simpler task to be performed and the lessening of energy requirements, a greater variety of loaders should be able to obtain a higher rate of fire with less training. The loading is more nearly machine-paced; therefore, performance should be consistent and uniform, permitting a more accurate "dead time" to be established for fuse setting purposes. The "dead time" should also be reduced. The changes would require relatively small additional weight, in the order of magnitude of a few hundred pounds rather than tons required for full automation. It is believed that most of the present hoist power drive may be used in the proposed design.

Testing of Proposed Method

Equipment Changes. A proposed method can be effectively evaluated only through actual application and, for this reason, the following changes were incorporated:

A rack was constructed at the machine that presented the ammunition as required in the proposed method. (See Figures 6, 7, 8). A lanyard was connected to a lever arm fastened to the rammer operating

8. Tiffin, Joseph, *Industrial Psychology*; Third Edition, New York, Prentice-Hall, Inc., 1952.



Fig. 6

A view from aft of the loading machine
and crew showing the proposed method

Conditions:

1. Rammer retract stroke in progress
2. Powderman commencing TL to tray
3. Projectile in rack being removed (DA)
4. Safety observers in upper left
5. Hot casemen in foreground center
6. Gun Captain to the right ready to drop spade.



Fig. 7

A view from aft of the loading machine
and crew showing the proposed method

Conditions:

1. Powder case loaded (PA) being steadied.
2. Projectile in process of TL to Tray.

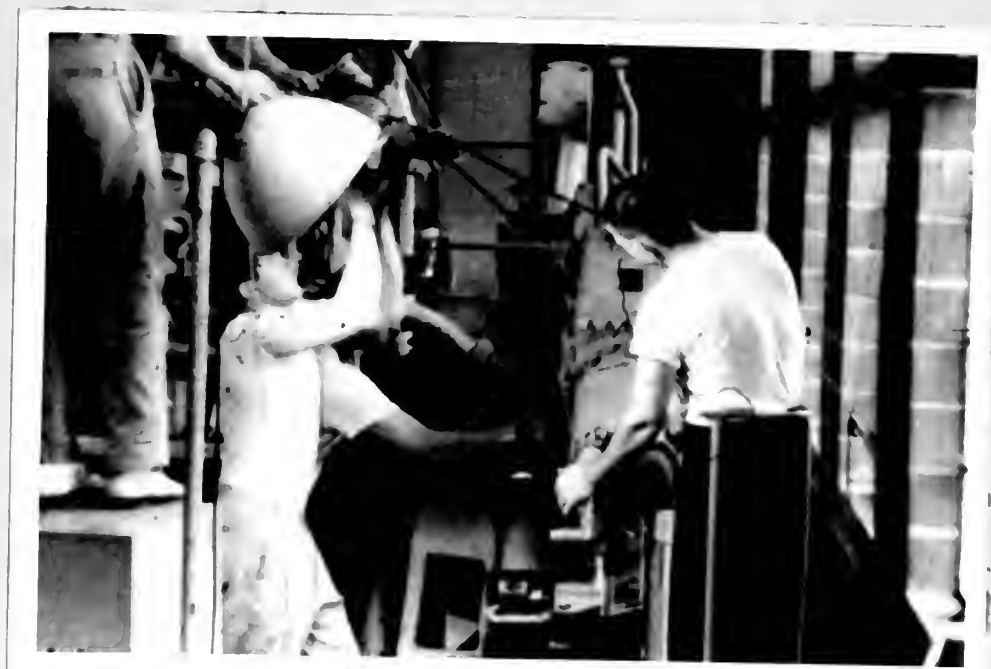
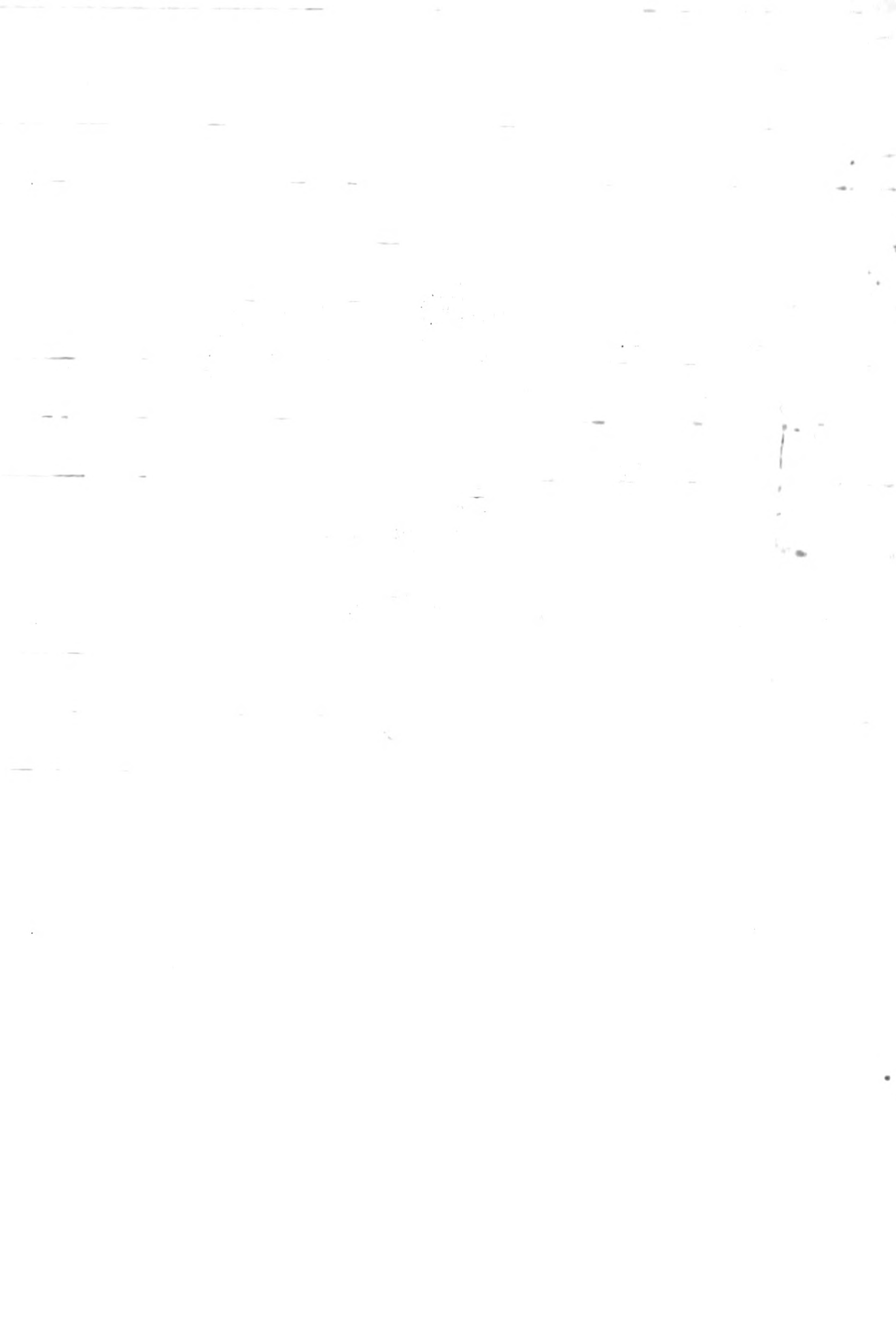


Fig. 8

A view from aft of the loading machine
and crew showing the proposed method.

Conditions:

1. Powder in tray.
2. Powderman grasping next round.
3. Projectile loaded (PA) and being steadied.
4. Gun Captain commencing to operate rammer control.



shaft and run to the Gun Captain's station. The releasing mechanism was foot-pedal operated to permit the ammunition to be removed from the end of the rack. The rack was constructed at an 8° angle from the horizontal. The rack was floored, but portions were cut away so that the round to be loaded was easily grasped from below. Other rounds were held back by the mechanism until the round was removed from the end of the rack. Release of the foot-pedal permitted the next round to index down. Safety observers were posted at each end to insure proper functioning and assist in feeding the ammunition. All loading was performed with the loading machine set at 30° elevation, determined to be the optimum for hot case ejection and handling.

Test Procedure. A nested factorial design with replication was used for the experimental design for the test.

Twelve loading teams (projectilemen and powdermen) were selected from volunteers from the freshman and sophomore classes of the N.R.O.T.C. Unit. These teams were selected so that they were divided equally into three groups based on weight and height. The weight and height limits for the groups were established from data on 3,075⁹ enlisted men. Group II was the middle size one-third \pm 0.43 standard deviations from the mean. Group I was made of large teams with height and weight greater than the mean, plus 0.43 standard deviations. Group III was

9. "Handbook of Human Engineering Data." Second Edition,

The Special Devices Center, Office of Naval Research, 1951.

made of small teams with weight and height less than the mean, minus 0.43 standard deviations. An attempt was made to minimize unwanted variables or at least to control them sufficiently to insure bias in favor of the present method. Instructions and demonstrations in the proposed method were given to all simultaneously. All had received several drills and previous instruction in the present method. All were given two additional drills in the present method. All teams loaded only between 5 and 15 rounds in the present method before loading for record. In order to reduce the effect of training during the test and of fatigue, each team loaded by each method twice in a controlled sequence as follows:

A - Proposed Method

B - Present Method

Group I Sequence of Loading

Team 1. A B B A

Team 2. A B A B

Team 3. B A A B

Team 4. B A B A

Groups II and III Sequences of Loading were the same as that of Group I.

Because of personnel casualties, lack of time, and the difficulty of scheduling a time convenient for a required minimum of eight men necessary to operate the machine, it was not possible to complete the

loadings of the first team in each group, i.e., sequence A B B A. The results shown are based on nine teams, three in each group, with sequence 2, 3, and 4, as listed above.

Each team was given a 5 to 15 round warm-up in each method. The warm-up for the proposed method was their first trial of that method. The predetermined sequence was carried out, each loading consisting of a 10-round, stop-watch timed, rapid fire sample. The readings were converted to a round per minute rate basis. A minimum of five minutes rest period was given between each loading to allow recovery from muscular work. Manzer¹⁰ found that better than eighty per cent recovery would be realized in this time.

Some factors affecting the motivation and performance of the teams were as follows:

1. They were all volunteers and entered into the project with customary collegiate zeal.
2. They all received the same "pep talk" on the aim and importance of the project.
3. A competitive spirit was developed and all teams were told each score after loading.
4. An attempt was made to minimize fear or apprehension of the temporary rig of the proposed system by flooring in the rack, stationing safety observers, showing each team the principle of the mechanism, and by first demonstrating and then requiring the teams to hold their hands on a round

10. Ibid.

in the tray while it was being rammed. Albeit, it is felt, however, that the "Heavy, Heavy, Hangs Over Your Head" effect was still present during the trial, at least during the first loading. It seems logical to expect that this effect would be largely eliminated in a permanent design.

5. Temperature, humidity, and light were not controlled, but were not considered adverse. Smoking was permitted between loadings.

After the regular part of the test procedure, movies were taken at 24 frames per second of Team 2 using the proposed method. Two loadings, of seven rounds each, were filmed. These were the fourth and fifth times that Team 2 had loaded using the proposed method. The first time was for training and no rate was recorded. The rates obtained in the order in which they were obtained were 26.0, 26.9, 27.8, and 28.8 rounds per minute.

Results of Test. The scores of the loadings are shown in Table 3. The means by group and method are shown in Table 4. The results of the F-test are shown in Table 5. A summary of statistical calculations is presented in Appendix B. The weight and height of the loaders is shown in Appendix A.

The results of the film analysis of the proposed method are shown in Tables 6 and 7. The film analysis showed that there was still ample room for further increase of rate of fire by this team through proper training.

TABLE 3

Results of Test Loadings in Rounds Per Minute

Team	Group I			Group II			Group III			
	1	2	3	4	5	6	7	8	9	
Proposed Method	1st	20.2	26.0	23.8	22.0	22.6	22.9	23.1	22.9	21.8
	2nd	24.1	26.9	24.9	23.5	24.6	25.0	22.9	23.7	23.5
Team Mean		22.15	26.45	24.35	22.75	23.60	23.95	23.00	23.30	22.65
Present Method	1st	14.2	18.0	12.5	14.1	14.0	13.7	14.1	12.2	12.7
	2nd	16.2	19.1	15.4	16.1	18.1	16.0	16.1	13.8	15.1
Team Mean		15.20	18.55	13.95	15.10	16.05	14.85	15.10	13.00	13.90

TABLE 4
Means by Group and Method
in Rounds per Minute

	Group I	Group II	Group III	Method
Proposed Method	24.32	23.43	22.98	23.58
Present Method	15.90	15.33	14.00	15.08
Difference	8.42	8.10	8.98	8.50

TABLE 5

Results of F-Test

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F	F.05	F.01
Between Methods	1	650.24	650.24	281.	4.41	8.28
Between Teams	2	15.74	7.87	1.23	5.14	10.92
Within Group	6	38.30	6.38			
Met X Team	2	1.21	0.605	0.261	5.14	10.92
inter-action			Reciprocal	3.83	19.33	99.33
Within Group and Method	6	10.82	1.80	0.776	2.66	4.01
			Reciprocal	1.29	3.90	7.46
Error	18	41.75	2.32			
Total	35					

TABLE 6
RESULTS OF FILM ANALYSIS--PROPOSED METHOD

Machine Analysis

Description	Loading Machine after Adjustment Time in seconds	Actual Gun Time in seconds
Operate control lever	0.12	0.13
Ram stroke	0.54	0.55
Breech block closed	0.13	0.15
Rammer retract stroke	0.54	0.41
Firing to Hot Case Clear	0.67	0.65
Retract Complete to Case Clear	0.13	0.23
Drop spade (after case clear)	0.10	
TOTAL CYCLE		
Commence Ram to Case Clear (Ready for next round)	1.34	1.35
TOTAL CYCLE		
Operate Ram Lever to Case Clear	1.46	1.48
Time from Case Clear to Ram Next Round	0.77	
Percent of Machine Utilization at 28.8 rounds per minute		
= $\frac{\text{Machine Cycle}}{\text{Total Cycle}}$	70.0	71.0



TABLE 7

RESULTS OF FILM ANALYSIS - PROPOSED METHOD

Man Analysis

Projectileman
28.8 Rounds per Minute

Therblig	Description	Time in Seconds	Minimum Observed
G	Grasp projectile	0.08	0.08
UD	Wait for hot case ejection	0.67	0.37
U	Depress foot pedal	0.17	0.17
DA	Remove projectile from rack (hoist)	0.50	0.42
TL	To Loading Tray	0.08	0.08
PA	Place in tray and steady	0.25	0.17
RL	Release projectile (ready for ram)	0.25	0.21
TE	To next round	0.08	0.04
	Release projectile to ram commenced	0.13	0.04
	Place in tray to Ram commenced	0.33	
	Place powder case in tray to place projectile in tray	0.37	0.12
	TOTAL CYCLE	2.08	1.60
	Time from Depress Foot Pedal to Ram	1.50	1.20

Note:

Minimum observed readings are the minimum for element observed in 12 cycles. The total 1.60 represents a rate of 37.5 rounds per minute. This rate was not obtained but shows a possible area for training.

Minimum complete cycle in 12 observed 1.92 sec., (rate 31.3)

Maximum complete cycle in 12 observed 2.40 sec., (rate 25).

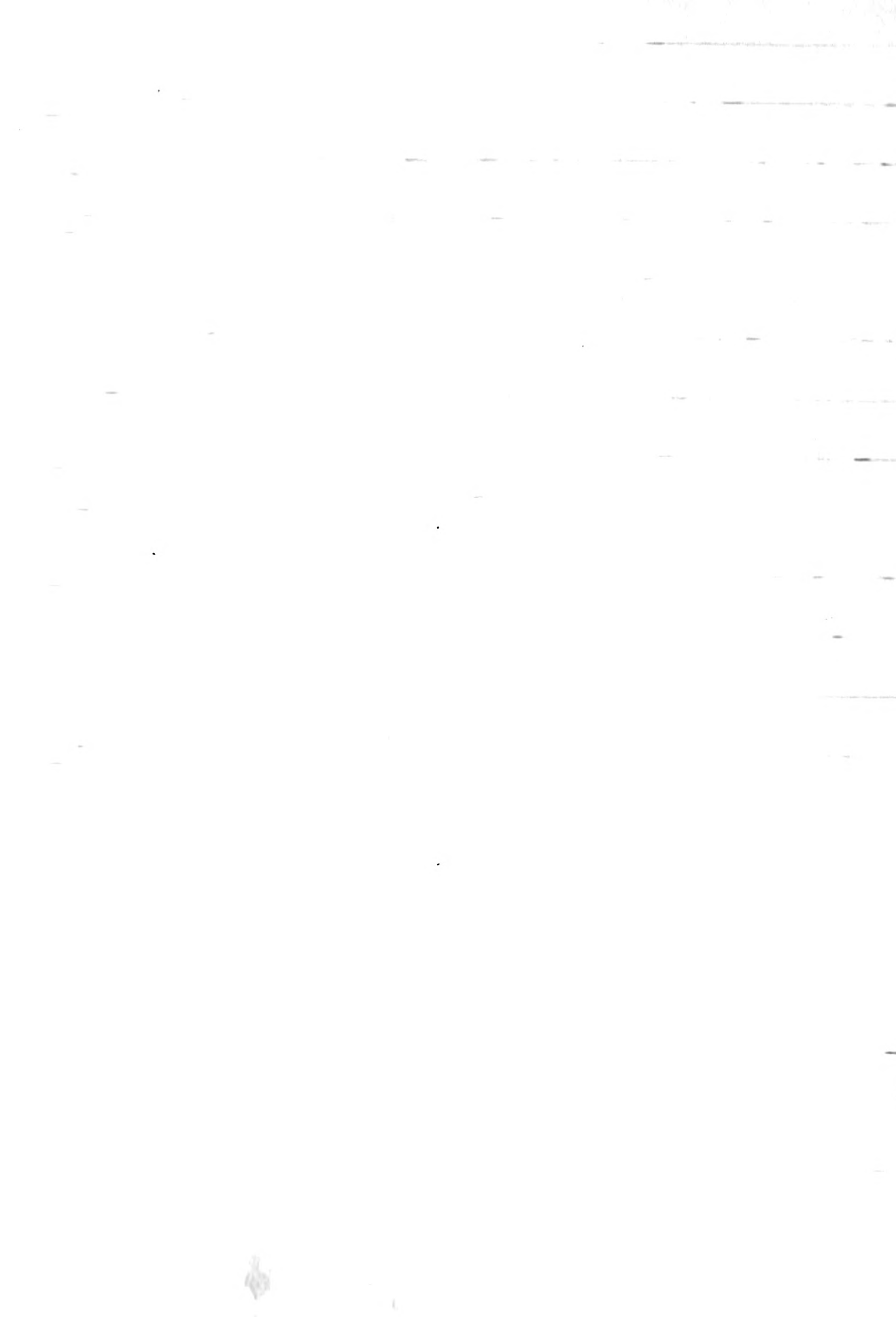


TABLE 7 (continued)

Man Analysis

Powderman

Therblig	Description	Time in Seconds	Minimum Observed
G	Grasp case	0.08	0.08
UD	Wait for hot case ejection	0.56	0.37
U	Depress foot pedal	0.33	0.33
DA	Remove case from rack	0.58	0.58
TL	To Loading Tray	0.08	0.04
PA	Place on tray and steady	0.25	0.25
RL	Release case	0.12	0.08
TE	To next case	0.08	0.04
TOTAL CYCLE		2.08	1.77
Time from "Hot Case Clear" to "Place in Tray"		0.08	0.04

Note:

The element "Remove Case from Rack" contains some "Wait" that was undetermined but estimated at approximately 0.25 seconds.

Minimum Complete Cycle in 12 observed was 1.8 seconds.

Discussion of Results of Tests. In designing the test it was hypothesized:

1. That there would be a difference between the loading rates of the two methods, the proposed method being significantly higher than the present method.
2. That there would be a significant difference between groups as selected in performing the present method, but there would be no significant difference between groups in performing the proposed method.
3. That the variability among teams in performing the present method would be greater than that in performing the proposed method.
4. That teams with little training on the proposed method could obtain a higher rate of fire than would be realized by the well-trained crew using the present method.

The results of the analysis of variance show that:

1. The first hypothesis was proved. The F-test showed that there was a significant difference between the methods well below the one per cent level. The difference of the means of the two methods obtained was 8.5 rounds per minute.
2. The second and third hypotheses were not proved. The F-test showed that there was no significant difference between groups. The differences could well have been caused by chance. On the other hand, the F-test did not prove that chance was the cause of the differences. The hypotheses should not be

discarded, but should be re-tested with well trained crews. A larger sample with longer periods of loading should be used to obtain the readings. It seems logical to expect that training would permit the proposed method scores to be more nearly machine-paced and that the longer periods of loading would allow fatigue to affect the present method scores (and the proposed method scores, but to a lesser degree if our assumptions are correct). On the other hand, it may be that weight and height are not proper criteria for selecting groups. Perhaps strength and endurance might be better criteria.

3. There is much evidence to support the fourth hypothesis. The teams were certainly not highly trained, since they had only loaded from 5 to 15 rounds before loading for score. The mean obtained was 23.58 rounds per minute. Computation of ninety-five percent confidence limits shows that the minimum mean to be expected at this level with this degree of training and other similar conditions is 22.37 rounds per minute. This minimum mean is greater than the maximum rate ever reported by the Fleet (22 rounds per minute) in using the present method.
4. There was no significant interaction found between method and group.
5. Applying ninety-nine percent confidence limits to the difference in means of the two methods shows that under similar conditions the difference in means between the two methods will be between

7.1 and 9.9 rounds per minute.

Although not a part of the statistical evaluation, the following indications of the loaders' attitudes are reported. After the teams had completed their test loadings each loader was asked the following questions:

(1) Which method do you prefer?

(2) Which method is easier to perform?

The answers to both questions were unanimously for the proposed method. Considerable skepticism was evident before they had tried the proposed method. After loading, most of the loaders seemed surprised at their own performance. The third question asked each loader was:

(3) Do you feel you could do better with more practice or have you reached your maximum?

The answers were that they could improve in both methods and did not feel that their maximum had been reached.

This was not a formal attitude survey nor was any attempt made to eliminate bias by obtaining anonymous answers.

CONCLUSIONS AND RECOMMENDATIONS

In view of the results obtained in this study, it can be concluded that the proposed method is highly desirable and is a considerable improvement over the present method. It can also be concluded from the micromotion studies that even higher rates than were obtained are possible.

It is recommended:

1. That further evaluation be made to determine the maximum performance that can be obtained with fully trained crews, investigating performance at maximum elevation and maximum depression and determining the maximum sustained rate that can be obtained.
2. That a design study be made to determine the feasibility of modifying the hoist system in the manner suggested.
3. That on the basis of this study, a prototype of the ready-service rack proposed as an interim alteration be designed and manufactured for use in the evaluations recommended in (1) above.
4. That prior to re-design of the hoist, a motion study similar to this be conducted in the Upper Handling Room to insure that the supply of ammunition required by the proposed method can be maintained.
5. That a study be conducted to determine a means of ejecting hot cases from the tray at angles of elevation greater than forty degrees.

APPENDIX A

Weight and Height of Loaders

APPENDIX A

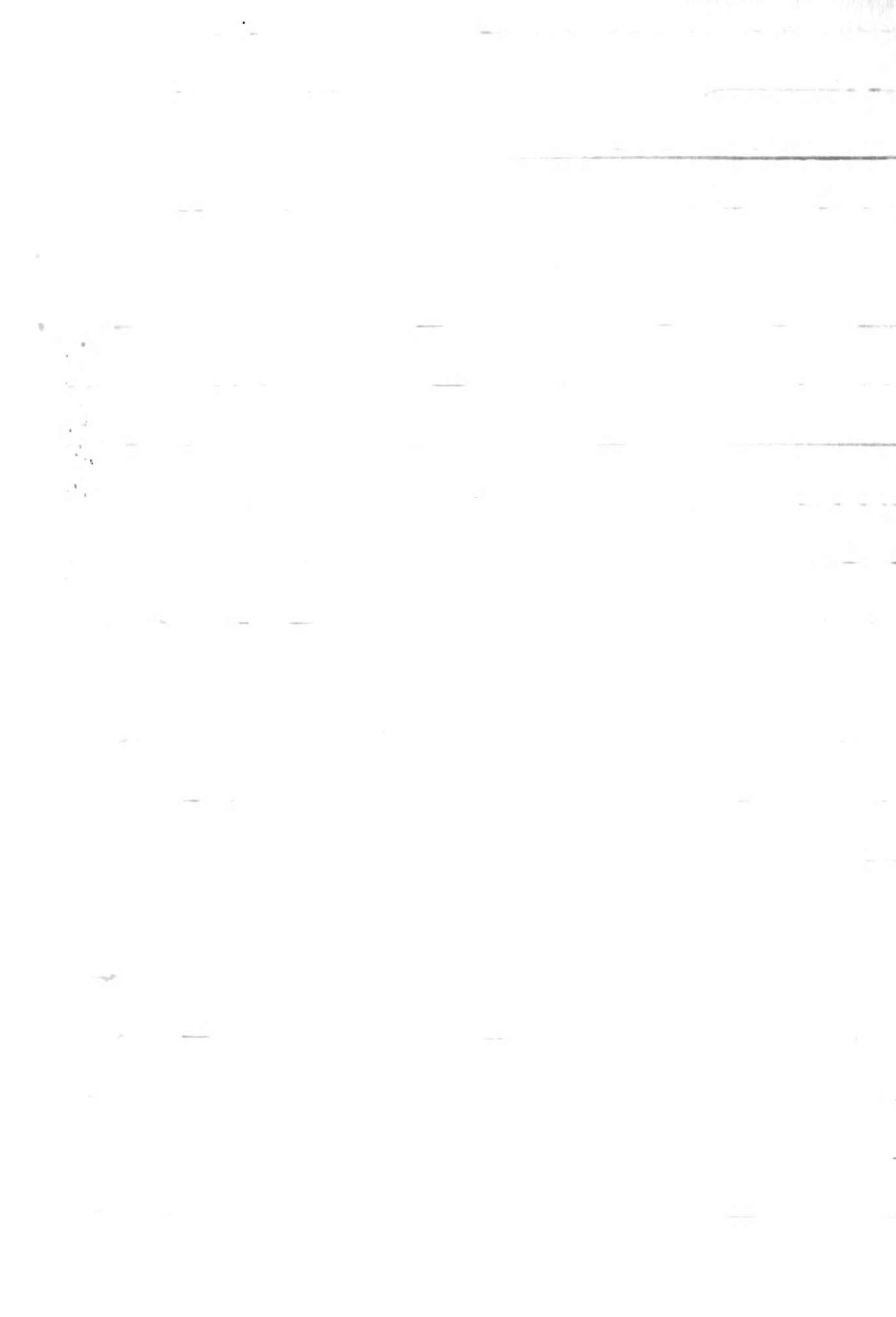
HEIGHTS AND WEIGHTS OF LOADERS

Group	Team	Powdermen		Projectilemen	
		Weight (lbs)	Height (inches)	Weight (lbs)	Height (inches)
I	1	185	71	180	74
	2	175	74	178	73
	3	180	73	195	73
Limit		169	70.3	169	70.3
II	4	160	69	168	69
	5	169	69	160	69
	6	165	69	165	69
Limit		151	67.9	151	67.9
III	7	150	67.5	151	67.75
	8	140	67	138	67
	9	145	67.75	145	67.5

All men were of athletic build and apparently in good physical condition.

APPENDIX B

Summary of Statistical Calculations



APPENDIX B

SUMMARY OF STATISTICAL CALCULATIONS

ANALYSIS OF VARIANCE

Code: A = Proposed method readings Met = method
 B = Present method readings
 Q = Variation or sum of squares

σ^2 = Population variance or mean square

$$Q = \Sigma A^2 + \Sigma B^2 - \frac{\Sigma A + B}{36}^2 = \underline{758.06}$$

$$Q_{Met} = \frac{\Sigma A}{18}^2 + \frac{\Sigma B}{18}^2 - \frac{\Sigma A + B}{36}^2 = \underline{650.24} \quad df = 1 \quad \sigma_{Met}^2 = \frac{Q_{Met}}{1} = \underline{650.24}$$

$$Q_{Btwn Teams} = \Sigma \frac{\Sigma A + B}{4}^2 - \frac{\Sigma A + B}{36}^2 = \underline{54.04}$$

$$Q_{e, Within team and met} = \Sigma \frac{A^2 + B^2}{2} - \frac{\Sigma A + B}{36}^2 = \underline{41.75} \quad df = 18$$

$$\sigma_e^2 = \frac{Q_e}{18} = \underline{2.32}$$

$$Q_{among cell teams and Met} = \frac{\Sigma A^2 + \Sigma B^2}{2} - \frac{\Sigma A + B}{36}^2 = \underline{716.31}$$

$$Q_{Team \times Met} = Q_{Team \& Met} - Q_{Met} - Q_{Btwn teams} = 12.03$$

$$Q_{Btwn Grs.} = \Sigma \frac{\Sigma A + B}{12}^2 - \frac{\Sigma A + B}{36}^2 = \underline{15.74} \quad df = 2$$

$$\sigma_{Btwn Gr.}^2 = \frac{Q_{Btwn gr.}}{2} = 7.87$$

$$Q_{Within Gr.} = Q_{Btwn Teams} - Q_{Gr} = \underline{38.30}$$

APPENDIX B (continued)

$$Q_{\text{Among Met \& Gr}} = \frac{\sum \bar{\Sigma A}^2}{6} + \frac{\sum \bar{\Sigma B}^2}{6} - \frac{\sum \bar{\Sigma A + B}^2}{36} = 667.19$$

$$Q_{\text{MetXGr}} = Q_{\text{among Met \& Gr}} - Q_{\text{Btwn Gr}} - Q_{\text{Met}} = 1.21 \quad df = 2$$

$$\hat{\sigma}_{\text{MetXGr}}^2 = \frac{Q_{\text{MetXGr}}}{2} = 0.605$$

$$Q_{\text{Within Gr \& Met}} = Q_{\text{MetXTeam}} - Q_{\text{MetXGr}} = 10.82 \quad df = 6$$

$$\hat{\sigma}_{\text{within Gr \& Met}}^2 = \frac{Q_{\text{within Gr \& Met}}}{6} = 1.803$$

Check*

$$Q_e = Q - Q_{\text{Btwn Teams}} - Q_{\text{Met}} - Q_{\text{MetXTeam}} = \underline{\underline{41.75^*}}$$

See Table 5 for results of F-Test.

Null Hypotheses:

1. The methods do not differ. ----- rejected.
2. There is no difference between groups -- not rejected--random causes.
3. Method X Group interaction effects are zero -- not rejected--random causes.
4. Within Group and Method Variation effects are zero -- not rejected -- random causes.

Since $\hat{\sigma}_e^2 > \hat{\sigma}_{\text{within Gr \& Met}}^2$ and Hypothesis 4 is not rejected then $\hat{\sigma}_e^2$ will be used to test providing most conservative test.

$\hat{\sigma}_{\text{within groups}}^2$ will be used to test $\hat{\sigma}_{\text{Btwn groups}}^2$.



APPENDIX B (continued)

$$F_{\text{Btwn Met}} = \frac{\hat{\sigma}_{\text{Btwn Met}}^2}{\hat{\sigma}_e^2} = 281$$

$$F_{\text{Btwn Grs.}} = \frac{\hat{\sigma}_{\text{Btwn Grs.}}^2}{\hat{\sigma}_{\text{Within Gr.}}^2} = 1.23$$

$$F_{\text{MetXGr.}} = \frac{\hat{\sigma}_{\text{MetXGr}}^2}{\hat{\sigma}_e^2} = 0.261 < 1$$

$$= \frac{\hat{\sigma}_e^2}{\hat{\sigma}_{\text{MetXGr}}^2} = 3.83$$

$$F_{\text{Within Group and Met}} = \frac{\hat{\sigma}_{\text{Within Group and Met}}^2}{\hat{\sigma}_e^2} = 0.776 < 1$$

$$= \frac{\hat{\sigma}_e^2}{\hat{\sigma}_{\text{Within Group and Met}}^2} = 1.29$$

95% Confidence limits on proposed Method Mean =

$$\text{Mean } \bar{X}_A \pm 2 \sqrt{\frac{\hat{\sigma}_e^2}{n_A}} = 23.58 \pm 2 \sqrt{\frac{2.3}{18}} = 23.58 \pm 0.71$$

APPENDIX B(continued)

99% Confidence limits on proposed method difference of means =

$$\bar{X}_A - \bar{X}_B \pm q(1, 35) \sqrt{\frac{\hat{\sigma}_e^2}{n}} = 8.50 \pm 1.37$$

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